Information for Policy Makers 2

Analysis of the EU's Energy Roadmap 2050 scenarios.

SEFEP working paper 2012

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He has more than 17 years professional experience in research and consultancy, concentrating on energy and climate change issues. He has published numerous studies and publications on German and international energy policy, as well as on environment and climate policy. Key topics of his work include the design, the comparison and the implementation of emissions trading schemes, energy market modelling and technology-specific policies (e.g. regarding cogeneration, nuclear energy) as well as the comprehensive assessment and monitoring of energy and climate policy packages. His key topic of interest in recent years has been the implementation of the EU ETS, including the phase-in of auctioning in phase 2 and 3 of the scheme.

He has served as a member of the in-depth review teams for National Communications under the United Nations Framework Convention on Climate Change (UNFCCC) for several occasions. From 2000 to 2002 he was a Scientific Member of the Study Commission ‘Sustainable Energy in the Framework of Globalization and Liberalization” of the German Federal Parliament (German Bundestag). In 2007 and 2008 he was a visiting scientist at the Joint Program on the Science and Policy of Global Change of the Massachusetts Institute of Technology (MIT) in Cambridge, MA.

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About SEFEP

SEFEP, the Smart Energy for Europe Platform, is an independent, non-profit organisation founded by the European Climate Foundation and the Stiftung Mercator. Based in Berlin, SEFEP offers a platform to stimulate cooperation and synergies among all European actors who aim to build a fully de-carbonised, predominantly renewable power sector.

Summary

With growing concerns about climate change, energy import dependency and increasing fuel costs, a political consensus has formed in Europe in recent years about the need to transform the way we supply and consume energy. However, there is less political consensus on the specific steps that need to be taken in order to achieve a future sustainable energy system. Questions about which technologies should be used to what extent and how fast changes in the energy system should be instituted are being discussed on the European Union as well as on the Member State level.

Energy scenarios are seen as a helpful tool to guide and inform these discussions. Several scenario studies on the European energy system have been released in recent years by stakeholders like environmental NGOs and industry associations. A number of these studies have recently been analysed by the Öko-Institut and the Wuppertal Institute within an ongoing project commissioned by the Smart Energy for Europe Platform (SEFEF).[1] The project aims to advance the debate on the decarbonisation of the energy system in the EU as well as its Member States during the course of 2012 and to make contributions to the scientific literature on this topic. Analysis within the project focuses on the development of the electricity system, as this system today is the main source for CO_2 emissions and is widely regarded to be the key to any future decarbonisation pathway.

The paper at hand summarises the analyses accomplished based on scenarios developed within the recently released Energy Roadmap 2050 of the European Union. The Roadmap explores different energy system pathways, which are compatible with the EU's long-term climate targets. It is a highly influential publication and will play a significant role in determining what will follow the EU's 2020 energy agenda. The Roadmap's analysis is currently discussed by EU and Member States policymakers as well as by stakeholders throughout Europe. Consequently it was a logical step within the SEFEP funded project to take a closer look at the seven different scenarios developed within the EU's Energy Roadmap 2050. As in the previous analysis of earlier energy scenario studies (SEFEP 2012) the main tool used to analyse and compare the scenarios is a decomposition method applied to show the extent to which technologies and strategies contribute to CO_2 emission reductions in the respective scenarios.

The results of the Energy Roadmap 2050 analysis mirror many of the project's earlier findings from other scenario studies: Renewable energy technologies are the most important supply-side element in the electricity sector for ambitious decarbonisation within the next four decades and wind will be the major contributor within the renewables. At the same time considerable energy efficiency improvements compared to a reference development are needed to limit growth in electricity demand and to simultaneously enable a significant amount of electricity to be used in the transportation sector to help reduce CO_2 emissions in that sector. The scenarios also indicate that CCS can be an important mitigation technology within the European electricity system, but that its future availability and public acceptance is limited and its importance for successful decarbonisation can be considerably reduced if a strong deployment of renewables can be achieved in the future.

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[1] See (Sefep 2012).

1. Introduction

At the UN climate conference in Cancún in December 2010, nearly all Parties expressed support for a target to limit global warming to a maximum of 2°C above pre-industrial levels, which is generally considered to be the threshold for global temperature rise to prevent the catastrophic consequences of climate change. The European Council subsequently reconfirmed in February 2011 that the objective of the European Union (EU) is to reduce its greenhouse gas emissions (GHGs) by 80 to 95 % below 1990 levels by 2050.[2] Although the EU is already committed to GHG emission reductions of at least 20 % below 1990 levels by 2020 as part of the Energy and Climate Package[3], longer-term policies are now required to ensure that the ambitious reduction target for 2050 is achieved. The European Commission has therefore published a 'Roadmap for moving to a competitive low-carbon economy in 2050'[4], providing guidance on how the EU can decarbonise the economy.

The process around this document which finally led to the EU's Energy Roadmap 2050 (European Commission 2011b)[5], published in December 2011, which is based on economic modeling and scenario analysis, which considers how the EU can move towards a low carbon economy assuming continued global population growth, increasing global GDP and by varying trends in terms of international climate action, energy and technological development.[6] The outcome of the analysis is a recommendation that the EU should reduce its domestic GHG emissions by 80 % below 1990 levels by 2050 and that this target is technically feasible and financially viable using proven technologies if strong incentives (i.e. carbon pricing) exist. The cost efficient pathway to achieve the 2050 target calls for domestic GHG reductions below 1990 levels of 25 % in 2020, 40 % in 2030 and 60 % in 2040 and this would require an additional annual investment of €270 billion for the next 40 years. This is equivalent to 'an additional investment of 1.5 % of EU GDP per annum on top of the overall current investment representing 19 % of GDP in 2009.'[7] The extent and timing of these GHG reduction targets are differentiated by sector reflecting the different abatement potentials that exist within the EU (Figure 1).

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[2] European Council (2011): Conclusions – 4 February 2011. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/119175.pdf

[3] The objective of the Energy and Climate Package is to reduce GHGs by at least 20 % by 2020 relative to 1990 emission levels, increase the share of renewable energy in meeting final energy demand in the EU to 20 % and to reduce energy consumption by 20 % compared to projected trends. See the annex for more information on how these policy objectives are to be achieved.

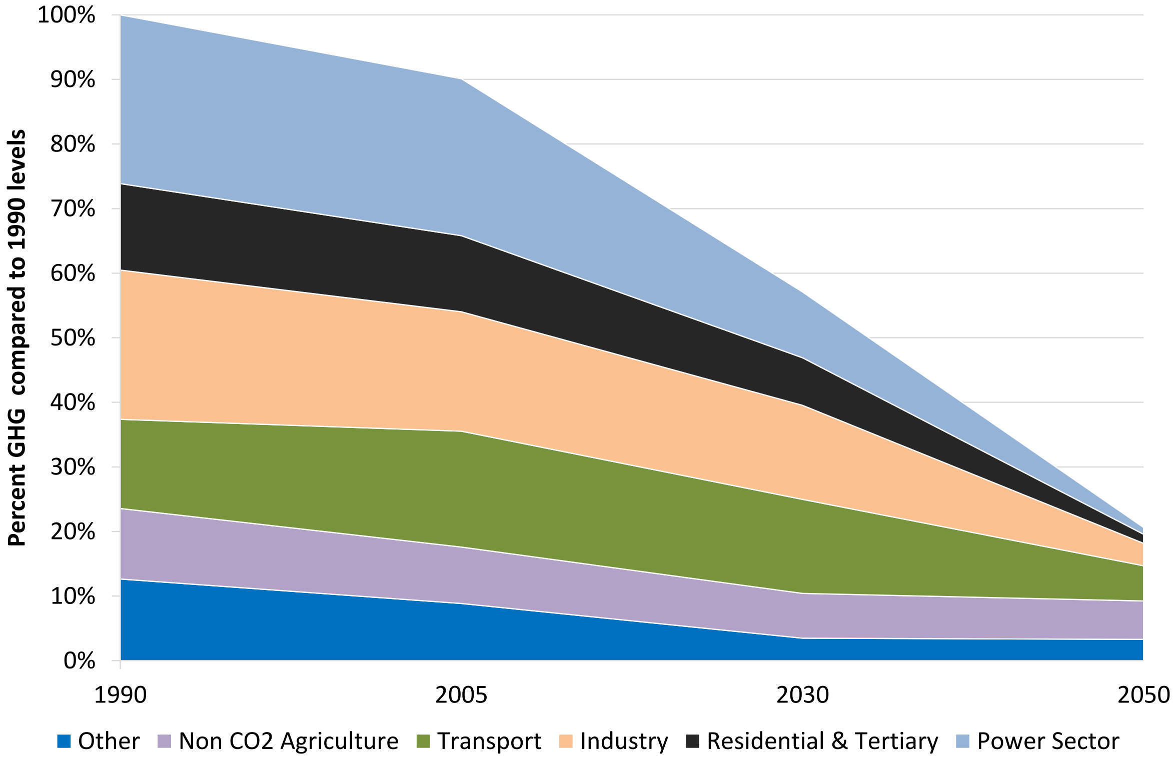
[4] COM (2011): A Roadmap for moving to a competitive low carbon economy in 2050. 112 final.

[5] COM (2011) 885/2.

[6] COM (2011): A Roadmap for moving to a competitive low carbon economy in 2050. 112 final.

[7] COM (2011): A Roadmap for moving to a competitive low carbon economy in 2050. 112 final.

Figure 1 EU Roadmap 2050 decarbonisation pathway



Source: (European Commission 2011a) and adapted by Öko-Institut / Wuppertal Institute (2012)

In December 2011, the final Energy Roadmap 2050[8] was published containing several scenarios based on the PRIMES model. The decarbonisation scenarios considered in the EU's Energy Roadmap 2050 reflect different views on how the EU can decarbonise its economy. For example, a decarbonisation scenario may differ based upon the use of technologies to generate electricity (i.e. renewable energy, nuclear and CCS) or may also differ due to how energy is used (i.e. rates of consumption and efficiency improvements). The objective of this policy paper is to provide a quantitative analysis of the similarities and differences of the following decarbonisation scenarios outlined in the EU's Energy Roadmap 2050:

- **Energy efficiency**: The scenario 'is driven by a political commitment of very high primary energy savings by 2050 and includes a very stringent implementation of the Energy Efficiency plan'. [9]

- **Diversified supply technologies:** All energy sources compete on a market basis in this scenario 'with no specific support measures for energy efficiency and renewables and assumes acceptance of nuclear and CCS as well as solution of the nuclear waste issue'. [10]

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[8] COM(2011) 885/2.

[9] SEC(2011) 1565/2.

- **High RES:** The scenario aims at 'achieving a higher overall RES share and very high RES penetration in power generation, mainly relying on domestic supply'.[11]

- **Delayed CCS:** The scenario 'follows a similar approach to the Diversified supply technologies scenario but assumes difficulties for CCS regarding storage sites and transport while having the same conditions for nuclear' as the Diversified supply technologies scenario.[12]

- **Low nuclear:** The scenario 'follows a similar approach to the Diversified supply technologies scenario but assumes that public perception of nuclear safety remains low and that implementation of technical solutions to waste management remains unsolved leading to a lack of public acceptance'.[13] The same conditions exist for CCS as in the Diversified supply technologies scenario.

The scenarios considered in this policy paper advocate a 'shared vision' for a decarbonised power sector in 2050 with a similar level of ambition with regards to CO_2 emission reductions in 2050. However, the scenarios under consideration have different views on the technology mix and levels of energy consumption and these differences are reviewed in regard to the electricity sector in Section 2. To provide further insights into the similarities and differences between the decarbonisation scenarios a decomposition analysis is completed in Section 3. The added value of this decomposition analysis is the ability to attribute the CO_2 emission reductions from a decarbonisation scenario to important causal factors such as the increase of wind power in the energy mix. The cost assumptions underlying these decarbonisation scenarios are considered in Section **Error! Reference source not found.**. The implications of the similarities and differences identified between all of the decarbonisation scenarios will then be discussed in Section 5 focusing especially on the timing of political action needed to realise the decarbonisation pathways. The paper concludes with Section 6.

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[10] SEC(2011) 1565/2.

[11] SEC(2011) 1565/2.

[12] SEC(2011) 1565/2.

[13] SEC(2011) 1565/2.

2. Shared vision of a decarbonised Europe

2.1 Emission trajectories

The decarbonisation scenarios all achieve CO_2 emission reductions in the power sector of at least 96 % below 2005 emission levels by 2050. The bullet point list below illustrates the hierarchy of ambition in regard to the power sector (i.e. emission reductions below 2005 levels by 2050) for the decarbonisation scenarios:

- Diversified supply (- 98.9 %)
- Low nuclear (- 98.6 %)
- Energy efficiency (- 98.4 %)
- Delayed CCS (- 98.2 %)
- High RES (- 96.3 %)

Many scenario studies that develop decarbonisation pathways first establish a reference scenario (i.e. emissions development without climate action). The EU's Energy Roadmap 2050 provides a reference[14] and a "Current Policy Initiatives" (CPI)[15] scenario which expect power sector CO_2 emissions to decline by 70 % and 61 % respectively below 2005 levels by 2050. Until 2030 the CPI scenario delivers more emission reductions than the reference scenario, reflecting additional measures adopted after March 2010. However, from 2030 onwards the reference scenario achieves greater CO_2 emission reductions than the CPI scenario and this may party reflect the impact of a phase down in the use of nuclear energy following the political impact of the Fukushima disaster in 2011 (Figure 2), reflected in the CPI but not the Reference scenario.

The emission development between 2020 and 2050 associated with the decarbonisation scenarios vary within a narrow range reflecting the different use of abatement options. All of the decarbonisation scenarios achieve the 2020 emissions target outlined in the Energy and Climate Package adopted by the EU in 2008. The Energy efficiency scenario achieves power sector CO_2 emission reductions at the highest rate of all scenarios until 2025, reflecting the implementation of the key policy initiatives adopted by the EU. The High RES scenario delivers the greatest emission reductions of all the scenarios by the end of 2030 and is then subsequently surpassed by the Delayed CCS scenario by the end of 2035. The Diversified supply and Low nuclear scenarios are characterised by a steady rate of CO_2 emission reduction over the 2020 to 2050 time horizon and all decarbonisation scenarios ultimately reach approximately the same level of CO_2 emissions by 2050 (Figure 2).

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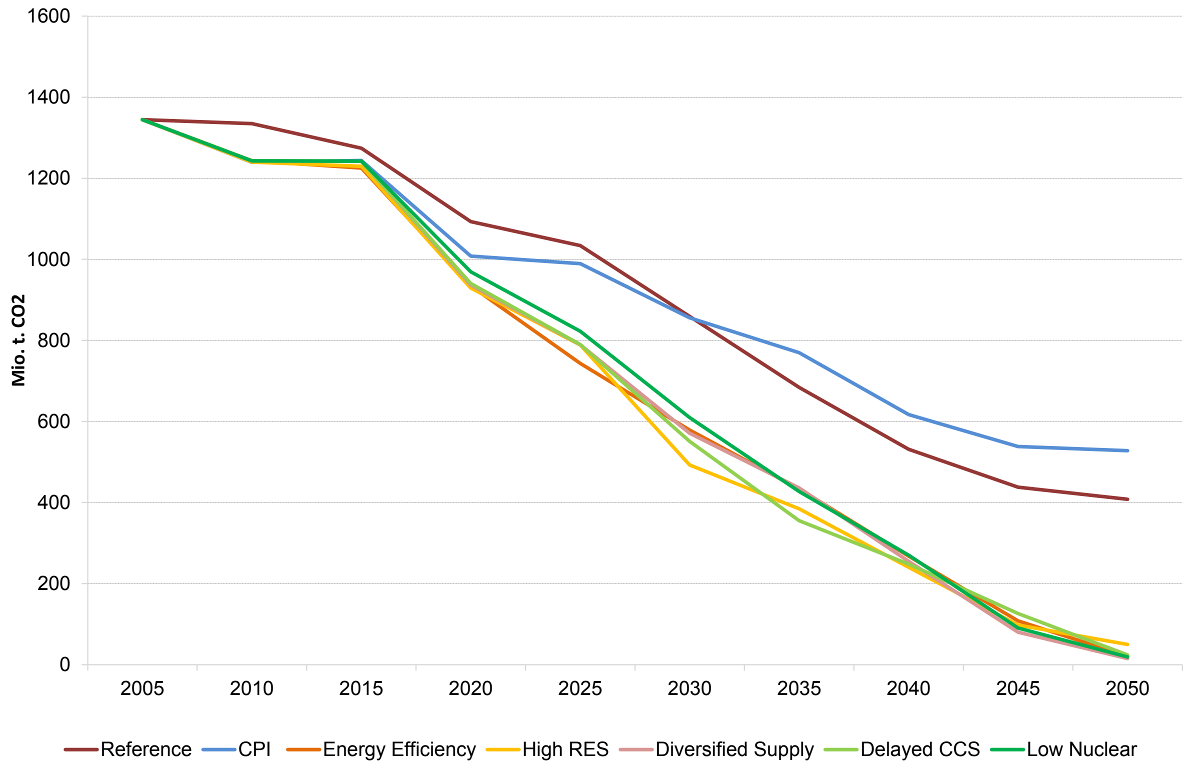
[14] 'The reference scenario includes current trends and long-term projections on economic development (GDP growth of 1.7 % p.a.). It takes into account rising fossil fuel prices and includes policies implemented by March 2010. The 2020 targets for GHG reductions and RES shares will be achieved but no further policies and targets after 2020 (besides the ETS directive) are modelled' (SEC (2011) 1565/2).

[15] The Current Policy Initiatives scenario also includes additional measures adopted after March 2010 in 'the area of energy efficiency, infrastructure, internal market, nuclear, energy taxation and transport. Technology assumptions for nuclear were revised reflecting the impact of Fukushima and the latest information on the state of play of CCS projects were included' (SEC (2011) 1565/2).

Figure 2 Power sector CO_2 emission trajectories for reference and decarbonisation scenarios



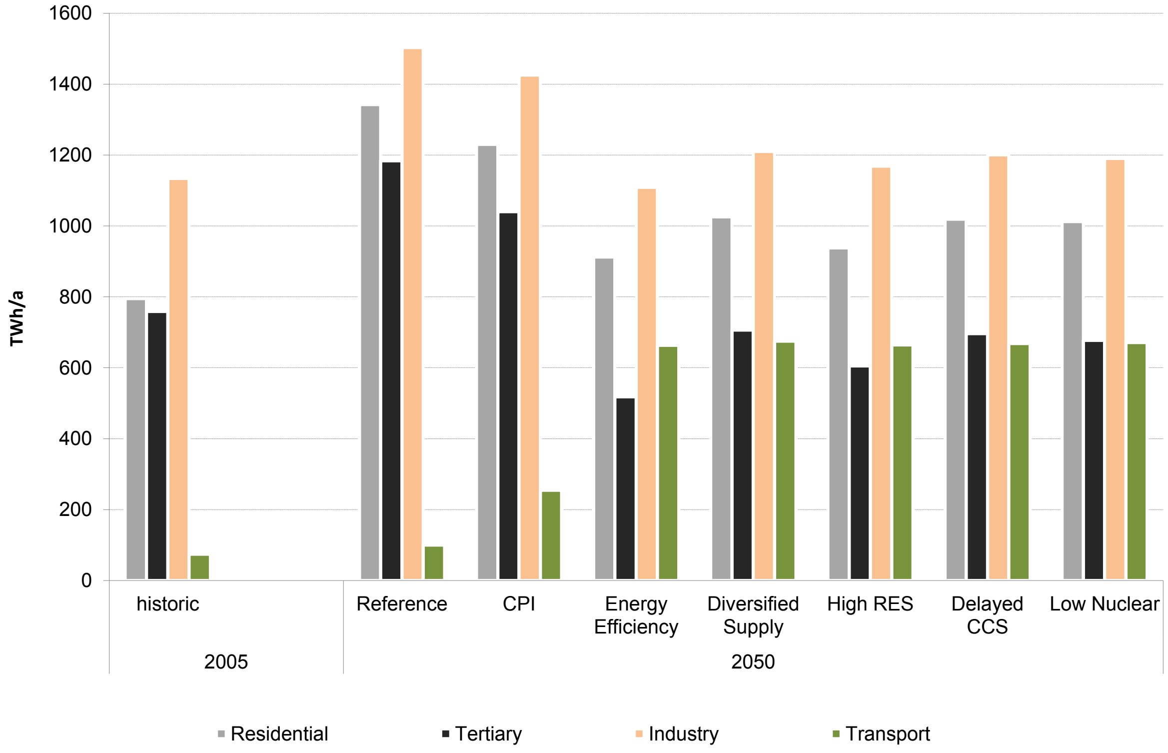
Source: Öko-Institut / Wuppertal Institute (2012), compiled from data kindly provided by DG Energy.

2.2 Electricity consumption

Total electricity demand in the EU-27 increases until 2050 in all seven scenarios of the EU's Energy Roadmap (Figure 3). However, in the decarbonisation scenarios the increase is less pronounced than in the CPI and especially the Reference scenario. While electricity demand increases by 50 % between 2005 and 2050 in the Reference scenario, the increase is between 16 and 31 % in the decarbonisation scenarios. The lowest increase occurs in the Energy efficiency scenario, where it is assumed that strong efficiency measures are implemented. Demand growth is also relatively low (+22 %) in the High RES scenario, where higher generation costs and higher market prices are assumed to have a dampening effect on electricity demand.

While considerable improvements in the efficient use of electricity are assumed in all of the decarbonisation scenarios (stronger so in the Energy efficiency scenario), these improvements are over compensated by additional demand for services requiring electricity. Some of that additional demand (for example in the case of electric cars and heat pumps) leads to lower non-electricity energy use and can thus help decarbonize the economy, but not the power sector as such if its supply technologies are not decarbonised in parallel. Figure 3 highlights the relevance that a future widespread use of electric cars could have on electricity demand. The vast bulk of additional electricity demand in 2050 (compared to 2005) occurs in the transport sector. Without this additional demand (inter alia for heat pumps) electricity consumption would actually drop in the Energy efficiency scenario and would be virtually flat in the High RES scenario, while it would increase only slightly in the other decarbonisation scenarios. Compared to a reference development, the EU's Energy Roadmap 2050 sees considerable potential for reducing electricity demand in all of the three other sectors (tertiary, households and industry). Electricity demand in the tertiary sector in 2050 could even be considerably lower than in 2005.

Figure 3 Electricity consumption (final energy demand) per sector in the EU-27 in 2005 and according to EU's Energy Roadmap scenarios in 2050 (in TWh/a)



Source: Öko-Institut / Wuppertal Institut (2012) compiled from data in European Commission (2011).

Previous European energy scenarios have made similar assumptions about the change in overall and sectoral electricity demand to be expected in any future decarbonised pathway. Figure 4 compares the changes in electricity demand between the base year and the year 2050 in three selected scenarios from the EU's Energy Roadmap 2050 (Reference, Energy efficiency and Diversified supply) with two other reference and four other decarbonisation scenarios from previous scenario studies.[16] All scenario studies see significant potential for efficiency improvements in the non-transport sectors compared to a business-as-usual development without strong efficiency measures. Realising these efficiency potentials could enable demand increases in these sectors to remain low, at or below 10 %. However, all scenarios expect electricity demand in the transport sector to increase dramatically,

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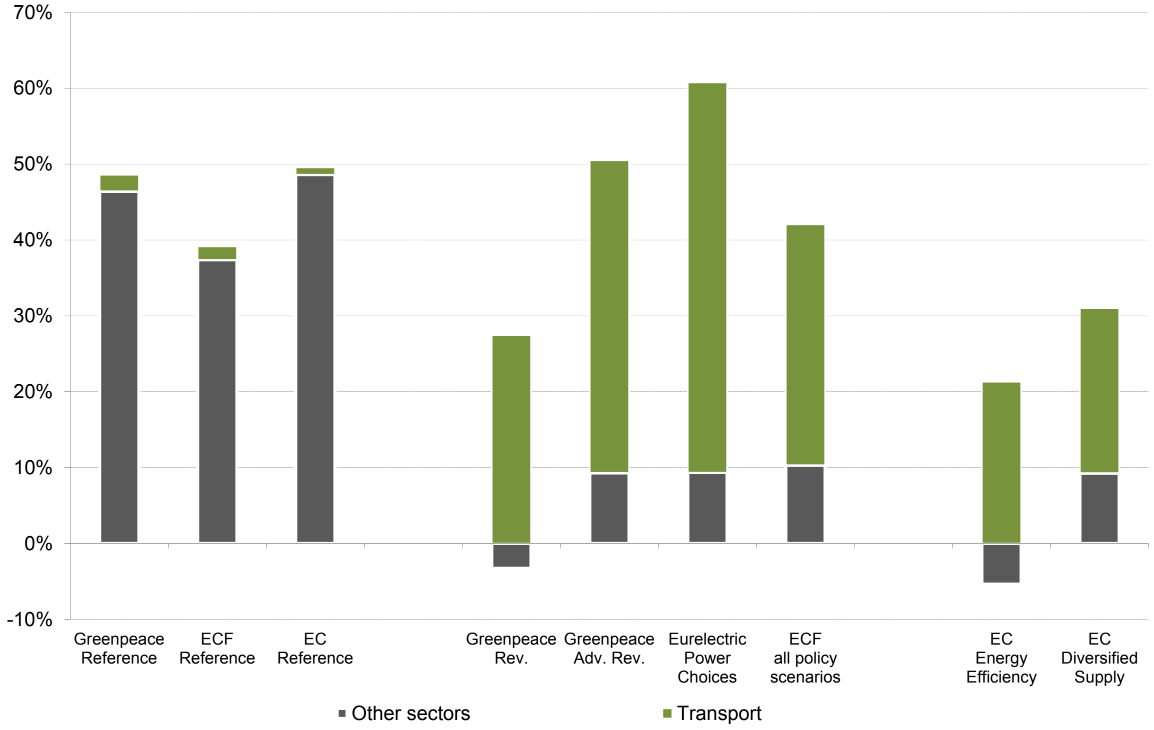
[16] See Sefep (2012) for more details on these other energy scenarios.

mostly due to the widespread introduction of full or hybrid electric cars. Compared to the policy scenarios of other studies, the decarbonisation scenarios of the EU's Energy Roadmap 2050 are a little more conservative regarding the future electricity demand in the transport sector. Interestingly, as evidenced by electricity demand in the reference scenarios, without adequate policy support, none of the studies compared here expect electricity to play a much larger role in the transport sector in 2050 compared to today.

Figure 4 Change in final electricity demand in the EU-27 from 2005/2007 to 2050 in various scenarios, differentiated by the transport sector and the other sectors

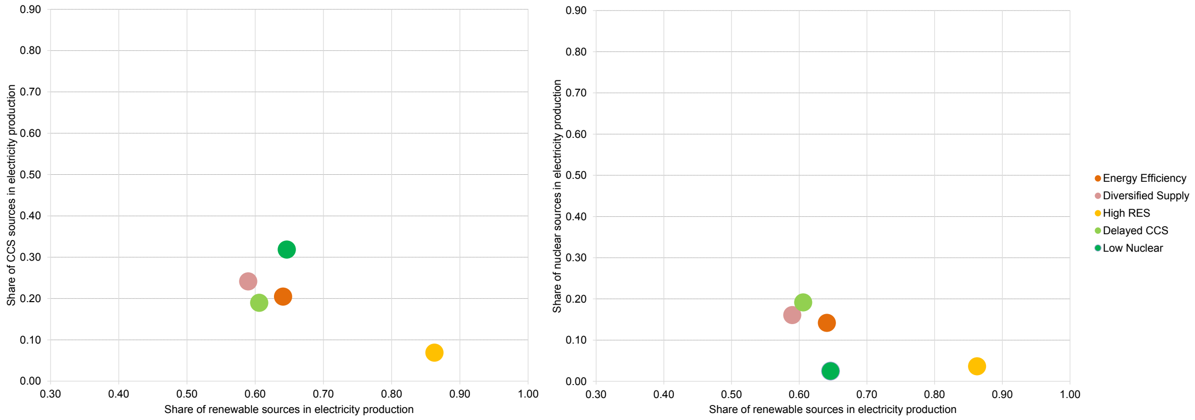


Source: Öko-Institut / Wuppertal Institute (2012) compiled from data in (European Commission 2011) (for the EU's Energy Roadmap 2050 scenarios) and (Greenpeace International & European Renewable Energy Council 2010; eurelectric 2009; European Climate Foundation 2010).

2.3 Sources of electricity production

In line with the overall objective of the decarbonisation scenarios, electricity generation in Europe in 2050 is based entirely or almost entirely on zero or low CO_2 emitting sources. However, the actual mixture of these zero or low CO_2 emitting sources is very different for the decarbonisation scenarios. Figure 5 shows that in 2050 renewable technologies dominate the electricity system, holding shares in gross electricity generation of 59 % (Diversified supply) to 86 % (High RES) in the decarbonisation scenarios. However, CCS power generation becomes an important element in the EU's power system, reaching shares of 19 % (Delayed CCS) to 32 % (Low nuclear) in most decarbonisation scenarios. Only in the High RES is CCS of little significance, contributing only 6 % by the middle of the century. The share of nuclear energy in 2050 is lower in all scenarios than today, falling from 27 % in 2010 to 26 % in the Reference and to only 2 % in the High RES and Low nuclear scenarios.

Figure 5 Share of electricity from renewable sources compared to the share of electricity from nuclear energy / CCS electricity generation for the decarbonisation scenarios by 2050



Source: Öko-Institut / Wuppertal Institut (2012), compiled from data kindly provided by DG Energy.

All of the individual factors described in this section (the sources of consumption and production of electricity), despite their different (technical) nature, have one characteristic in common: their level of use/non-use triggers changes in CO_2 emissions over time. The decomposition analysis in Section 3 uses this common denominator as a metric to derive the effect that each of these individual factors has on emission changes in a given decarbonisation scenario.

3. Comparison of decarbonisation scenarios

The overview in the previous section outlined the important similarities and differences with regards to the overall timing of CO_2 emission reductions, technologies deployed and rates of electricity consumption. However, this analysis is unable to attribute emission changes to the specific changes to the electricity system advocated in all of the decarbonisation scenarios. The objective in the following is therefore to quantitatively analyse all of the decarbonisation scenarios based upon decomposition techniques in order to determine how the causal factors drive changes in emissions.

3.1 Methodology

A decomposition analysis requires an equation that describes the influence of several causal factors on the observed changes of a variable of interest (CO_2 emissions). According to the decomposition equation developed for this policy paper[17], the total amount of CO_2 emissions can be determined by

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[17] $E_t = C_t(1-\pi_t^f)\frac{I_t}{P_t^{fos}}\frac{E_t}{I_t}$

the electricity consumption in the various sectors[18] which is being supplied, by the electricity production from a mix of different technologies[19] that differ in their need for fossil fuels[20] (old coal plants need more coal than new ones, wind farms need no fossil fuel) which in turn will have different emission factors[21], implying differing CO_2 emissions per energy unit (gas less than coal). An in-depth description of the decomposition equation is provided in the background document accompanying this policy paper entitled *WP 1.2: Comparison Methodologies*. Input data from all of the decarbonisation scenarios were collected and supplemented with transparent gap-filling techniques to ensure that the decomposition equation could be successfully executed.[22] Based upon the Laspeyres decomposition method, the isolated effect of a causal factor on the CO_2 emissions of the power sector in 2050 was calculated by changing the value of a causal factor to its scenario value in 2050 whilst ensuring that the remaining causal factors remain at their base year value. By replicating this calculation for all the causal factors, the outcome of the decomposition analysis is to attribute changes in emissions to changes in the consumption of electricity, the production of electricity from different technologies, the fossil fuel input and the different emission factors associated with the use of different fossil fuels.[23]

3.2 Results

The results of the decomposition analysis in the year 2050 are presented in

Figure 6 along with the respective electricity generation mix of the decarbonisation scenarios in Figure 7. The coloured bars in

Figure **6** for each decarbonisation scenario represent the CO_2 **emission change** from the base year due to different causal factors, which can either positively or negatively contribute to CO_2 emissions. For example, Figure 6 shows that additional CO_2 emissions would result from a phase out or the reduced use of nuclear power as illustrated by the negative dark blue segment while additional deployment of renewable energies (the positive green segment) would result in CO_2 emission reductions. The **net emission reduction** delivered by each decarbonisation scenario (actual emission

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[18] In the decomposition equation this is referred to as 'electricity consumption', C_t , which is defined as the consumption of electricity from various sectors at time step *t*.

[19] In the decomposition equation this is referred to as 'electricity production', $1-\pi_t^f$, which is defined as the share of production from CO_2 emitting electricity generation technologies at time step *t.*

[20] In the decomposition equation this is referred to as 'fuel input intensity', I_t/P_t^{fos}, which is defined as the fossil fuel input per unit of electricity production at time step *t*.

[21] In the decomposition equation this is referred to as 'emission factor', which is defined as the CO_2 emissions per unit of fossil fuel input at time step *t*, E_t/I_t.

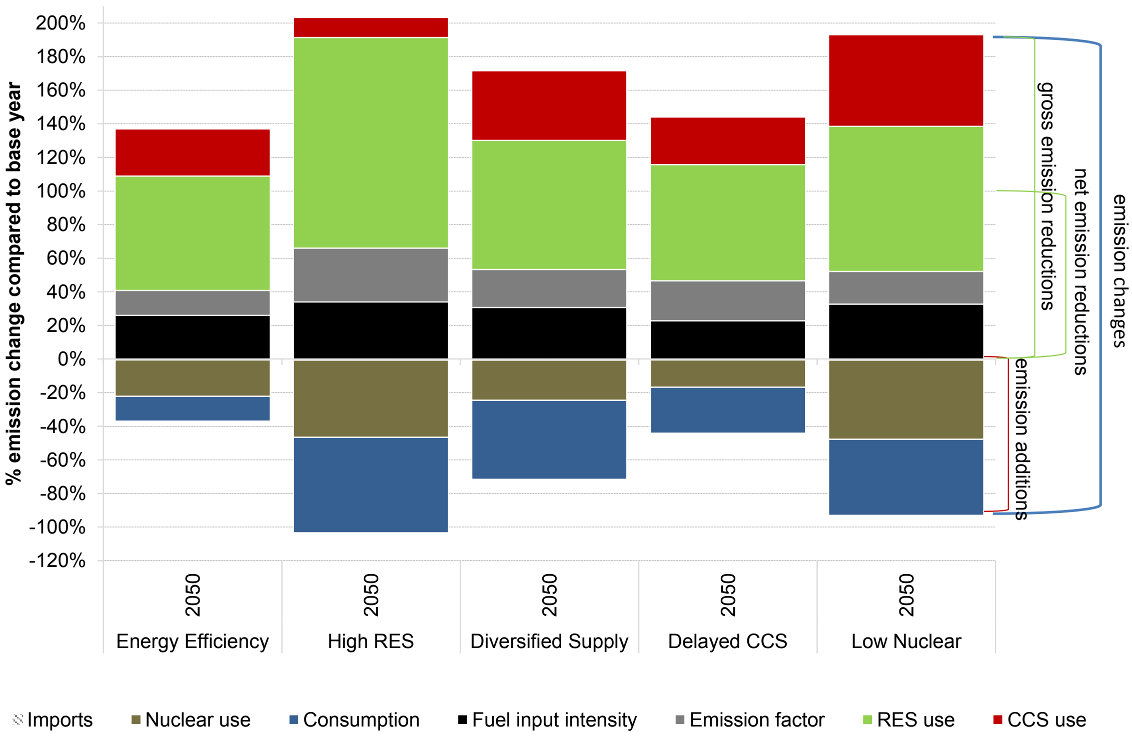
[22] See *WP 3.1. Quantitative Analysis of scenarios from the EU Energy Roadmap 2050* (hereafter WP 3.1.).

[23] The extent to which we can attribute the observed changes in the variable of interest to the explanatory factors depends upon the size of the residual from the decomposition. The residual occurs due to the 'mixed effect' of explanatory factors interacting with one another to contribute to the observed change in the variable of interest. The residual has been distributed to the causal factor proportional to their contribution to overall CO_2 emission changes. See also WP 1.2.

reductions) is determined by subtracting the **additional emissions** (negative segments) from the **gross emission reductions** (positive segments).[24]

The coloured bars in Figure 6 for each decarbonisation scenario represents the absolute contribution of an electricity generating technology, which is measured in TWh, in supplying electricity. For example, the absolute contribution of wind energy in supplying the total electricity of a decarbonisation scenario in the year 2050 is illustrated by the purple segment. It is important to acknowledge that the total electricity demand varies between the decarbonisation scenarios due to the different assumptions with regard to electricity consumption, which were previously discussed in Section 2.

Figure 6 Overview of the contribution of different causal factors to emission changes in 2050 compared to the base year



Note: The decomposition analysis was accomplished based on gross electricity production values. Thus, on the demand side, electricity consumption for conversion, line losses and consumption from refineries and other uses is included in the aggregate consumption depicted in the figure

Source: Öko-Institut / Wuppertal Institute (2012) results from the decomposition analysis

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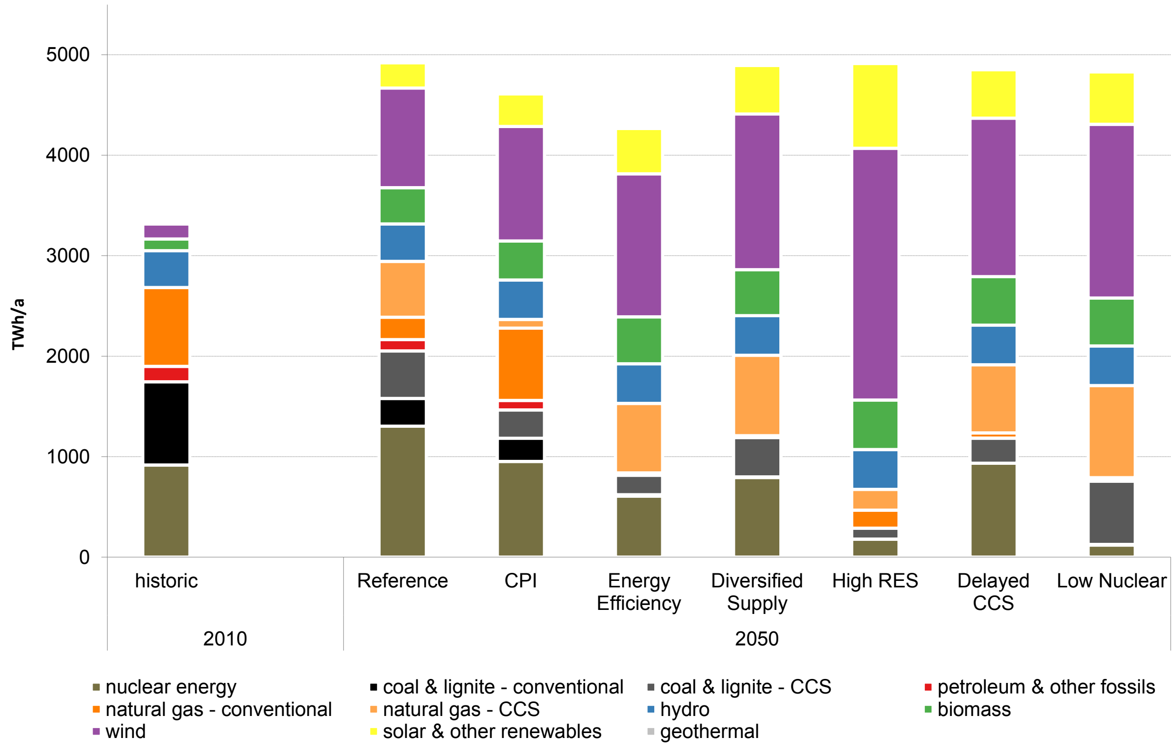
[24] The positive part of each column in **Figure 6** represents the gross emission reductions achieved by the causal factors. The positive part of each column is longer than the actual emission reductions achieved because additional emissions triggered by factors depicted in the negative part of each column need to be compensated for in order to reach the emission goal of each scenario which is equal to the net emission reductions achieved.

Figure 7 The electricity generation mix in 2010 and within the different scenarios in 2050



Source: Compiled from data kindly provided by DG Energy.

Figure 6 demonstrates the relationship between changes in emission levels (compared to the base year) and changes in the electricity generation mix that are associated with the different decarbonisation scenarios by the year 2050. For example, the rapid deployment of renewable energy technology envisaged in the High RES scenario represents 86 % of the electricity generation mix and is responsible for 125 % (60 % of the gross emission reductions by causal factors)[25] of emission changes by 2050. The emergence of CCS technology will also play an important role in emission reductions by the year 2050, especially in the Low nuclear scenario whereby CCS technology will eventually represent 32 % of the electricity generating mix and contribute to an emission change of -

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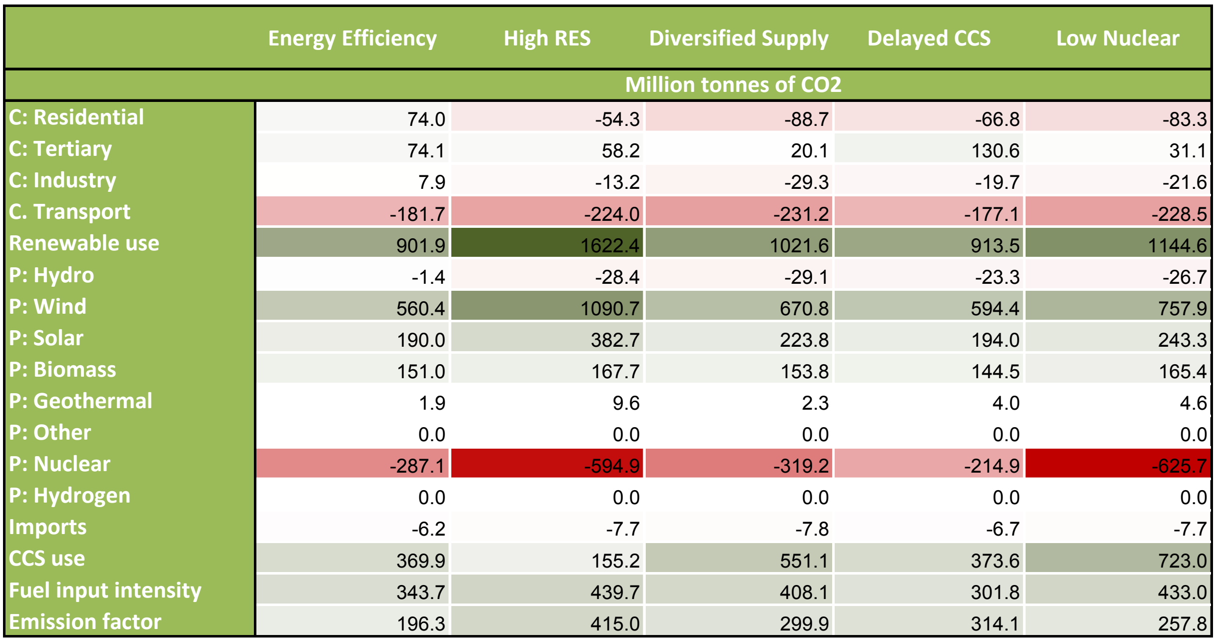
[25] The value in the bracket represents the share of that causal factor’s emission reduction on the gross emission reductions achieved by the causal factors. These shares are illustrated in the Annex for each scenario. Hereafter all brackets following text on emission changes will refer to the share of that causal factor’s contribution on gross emission reduction achieved by the causal factors.

55 % (28 % of the gross emission reduction by causal factors) by 2050. In contrast, the decline of nuclear energy to 3 % of the electricity generating mix by 2050 in the Low nuclear scenario will result in additional emissions of 47 % that will need to be offset by additional emission reductions (i.e. deployment of renewables, CCS). Additional emissions may also be generated via increased levels of electricity consumption by 2050; however the stringent efficiency measures applied in the Energy efficiency scenario considerably limit additional emissions from electricity consumption and this is reflected in Figure 7 as the absolute level of electricity production in the Energy efficiency scenario (4,281 TWh) is considerably lower in 2050 relative to the other decarbonisation scenarios.

Table 1 Decomposition results of CO_2 emission reduction in 2050 for the decarbonisation scenarios.



	Energy Efficiency	High RES	Diversified Supply	Delayed CCS	Low Nuclear
	Million tonnes of CO2				
C: Residential	74.0	-54.3	-88.7	-66.8	-83.3
C: Tertiary	74.1	58.2	20.1	130.6	31.1
C: Industry	7.9	-13.2	-29.3	-19.7	-21.6
C. Transport	-181.7	-224.0	-231.2	-177.1	-228.5
Renewable use	901.9	1622.4	1021.6	913.5	1144.6
P: Hydro	-1.4	-28.4	-29.1	-23.3	-26.7
P: Wind	560.4	1090.7	670.8	594.4	757.9
P: Solar	190.0	382.7	223.8	194.0	243.3
P: Biomass	151.0	167.7	153.8	144.5	165.4
P: Geothermal	1.9	9.6	2.3	4.0	4.6
P: Other	0.0	0.0	0.0	0.0	0.0
P: Nuclear	-287.1	-594.9	-319.2	-214.9	-625.7
P: Hydrogen	0.0	0.0	0.0	0.0	0.0
Imports	-6.2	-7.7	-7.8	-6.7	-7.7
CCS use	369.9	155.2	551.1	373.6	723.0
Fuel input intensity	343.7	439.7	408.1	301.8	433.0
Emission factor	196.3	415.0	299.9	314.1	257.8

Note: Negative values reflect emission additions, while positive values reflect emission reductions.

Source: Öko-Institut / Wuppertal Institute (2012), results from decomposition analysis.

The results of the decomposition analysis are illustrated further in Table 1, which outlines the absolute reduction in CO_2 emissions between the base year and 2050 attributed to each causal factor measured in million tonnes of CO_2. The CO_2 emission reduction is either negative and thus characterised by additional emissions (red shading) or is positive and characterised by emission reductions (green shading).

All of the decarbonisation scenarios analysed in this policy paper assume that electricity consumption will increase considerably for road transport and heat applications by 2050. This is due to the envisaged growth in new electric appliances (electric mobility, heat pumps), reducing CO_2 emissions by switching from other fuels to low carbon electricity. For example, the electrification of road transport is assumed in all of the decarbonisation scenarios, whereby 80 % of private passenger transport activity in 2050 will involve the use of plug-in hybrid or pure electric vehicles.[26] This trend is

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[26] SEC (2011) 1565.

dependent however upon political action, which will be necessary to facilitate the commercialisation of new appliances such as electric vehicles, which are currently too expensive for a widespread diffusion. For example, political action may consist of public investments in infrastructural developments (charging points) and tax subsidies to lower the capital costs associated with purchasing electrical vehicles. As a consequence of the increase in electricity consumption for both road transport and other new appliances used for heating in 2050, additional CO_2 emissions will be generated within the electricity system.[27] It is therefore essential that political action should be taken in parallel to transform the energy system so that low carbon technology is primarily used to generate electricity. It is important to acknowledge that in all decarbonisation scenarios, including even the Energy efficiency scenario, improvements in the efficiency of traditional applications in the residential, tertiary, industry and transport sectors will not entirely offset the increase in electricity consumption from the new appliances by 2050 as well as additional electricity consumption caused by GDP growth in any of the decarbonisation scenarios, given the base year's electricity mix.

The decomposition analysis demonstrates that an increase in the share of electricity generated from renewable technology will result in considerable emission reductions by 2050. All of the decarbonisation scenarios envisage that wind energy will account for the largest share of electricity generation from renewables in 2050. There is also a general consensus among the decarbonisation scenarios that an increase in solar and biomass energy will greatly contribute to emission reductions in 2050. The increasing deployment of renewables in all of the decarbonisation scenarios assumes that the capital expenditure cost of these technologies will reduce over time (see Section 4); however political action in the form of market deployment policies as well as public investment in the research and development of renewable technologies will be necessary for these cost reductions to materialise. Policy makers also need to address the existing barriers to the deployment of renewables (planning permission, capital costs) that considerably increase lead times. Access to capital and the fast-tracking of planning applications for renewables will be essential for realising the High RES scenario, which assumes that the total RES capacity would need to increase to over 1,900 GW by 2050 (this is more than eight times the current RES capacity).[28] Infrastructural investments in transmission grids and storage technology will also be necessary in the longer term to overcome issues concerning both the distribution of electricity and the intermittency of supply.

There is agreement amongst the decarbonisation scenarios that CO_2 emissions will be reduced by 2050 as a consequence of an increase in the average conversion efficiency of the remaining fossil fuel plants (an improvement in the fuel input intensity) and due to the fossil fuel input becoming cleaner (an improvement in the emission factor by fuel switch from coal to gas). All of the decarbonisation scenarios expect the average conversion efficiency of fossil fuel plants and the cleanliness of the fossil fuel input to improve by 2050. In particular, the Energy efficiency scenario is characterised by

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[27] Given that the decomposition analysis only calculates the 'isolated effect' of a causal factor, the emissions reduction from an increase in consumption is negative (i.e. additional emissions) as the energy mix remains the same as in the base year. The residual of the decomposition accounts for 'mixed effects' such as an increase in electricity consumption and an increase in the share of renewables in the energy mix and is distributed proportionally to each causal factor, so that the mixed effects are accounted for.

[28] SEC (2011) 1565.

the lowest rate of primary energy consumption of all of the decarbonisation scenarios with a reduction of 16 % in 2030 and 38 % in 2050 compared to 2005 and reflects the effect of stringent energy efficiency policies such as 'an obligation that existing energy generation installations are upgraded to the BAT every time their permit needs to be updated'.[29] The increasing efficiency of fossil fuel consumption and the switch from coal to gas envisaged in these decarbonisation scenarios may be further encouraged by reducing the subsidies associated with fossil fuel use and by setting CO_2 taxes to increase the cost of fossil fuel use.

The impact of nuclear energy use on emission change in all of the decarbonisation scenarios contributes to additional emissions by 2050. The political response of Member States such as Italy (i.e. abandoning substantial nuclear plans) and Germany (i.e. revision of nuclear policy) to the recent nuclear accident in Fukushima has been incorporated into the decarbonisation scenarios under consideration in this policy paper with lower expectations for the rate of nuclear penetration by 2050. For example, the share of nuclear use in the electricity generation mix declines to 2 % by 2050 in the Low nuclear scenario due to the underlying assumption that there is no new investment in nuclear capacity (except for plants currently under construction) and that investments into the extension of lifetimes of existing plants can only occur until 2030. Even under the most ambitious scenario for the penetration of nuclear energy (the share of nuclear energy in the electricity mix is 18 % by 2050 in the Delayed CCS scenario) the causal factor nevertheless contributes to additional emissions. This partly reflects the fact that the share of nuclear energy declines in all scenarios compared to the base year.[30]

All of the decarbonisation scenarios depend upon the emergence of CCS technology, albeit to varying extents, in order to reach the necessary level of emission reductions by 2050. It is assumed within the modelling exercise that the capital expenditure of CCS technology will be considerably reduced until 2030 and thereafter (see Section 4) enabling the abatement technology to be highly utilised in the Low nuclear scenario. The use of CCS technology is only constrained by barriers relating to the potential for CO_2 storage and transport, which are reflected in the lower contribution of CCS technology to emission changes in 2050 (18 % of gross emission reductions) in the Delayed CCS scenario. In order to realise all of the decarbonisation scenarios, significant investment in CCS technology will be required to ensure the widespread penetration of this abatement measure, which obtains the support of the general public with regard to the financing and construction of dedicated CO_2 transport grids.[31]

In order to provide policy makers with further insights into the importance of the timing of political action between 2020 and 2050 to reduce CO_2 emissions;

Figure 6 is extended in Figure 8 to show how the different causal factors contribute to CO_2 emission change at various time horizon intervals (i.e. 2020, 2030, 2040 and 2050) always compared to the

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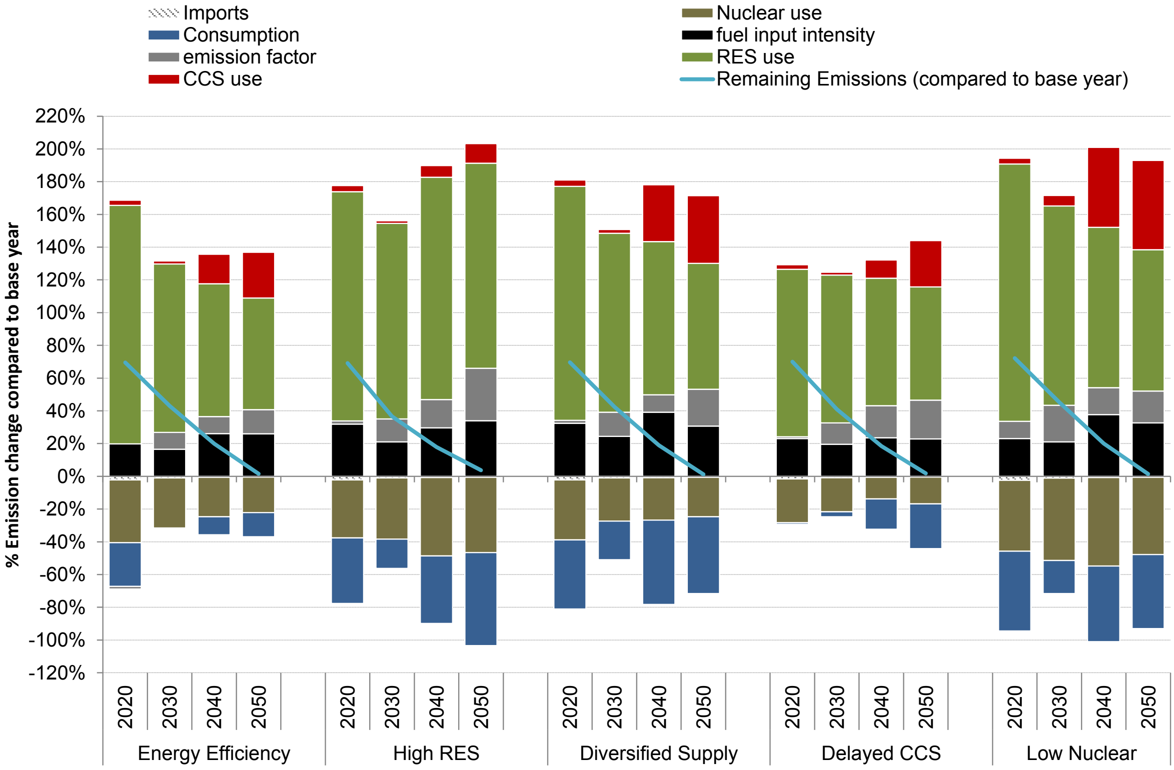
[29] SEC (2011) 1565.

[30] The residual produced by the decomposition analysis is higher in the delayed CCS scenario than in the others. This may be due to the gap filling assumptions that needed to be accomplished and which add uncertainty to the analysis. These assumptions are documented in WP 3.1

[31] SEC (2011) 1565.

base year. The emissions relative to the base year are illustrated in Figure 8 by the blue line for each decarbonisation scenario, which demonstrates that in all scenarios the gross emission reductions offset the additional emissions so that the power sector is nearly fully decarbonised by 2050.

Figure 8 Overview of the contribution to emission change from the base year of different causal factors in the decarbonisation scenarios between 2020 and 2050



Note: The decomposition analysis was accomplished based on gross electricity production values. Thus, on the demand side, electricity consumption for conversion, line losses and consumption from refineries and other uses is included in the aggregate consumption depicted in the figure.

Source: Öko-Institut / Wuppertal Institute (2012)

Although all of the scenarios achieve an almost fully decarbonised power sector in Europe by 2050, the combinations of causal factors differ between the decarbonisation scenarios, which influence the overall timing of CO_2 emission reductions. For example, the High RES scenario – as its name suggests – depends primarily upon the deployment of renewable energy to reduce CO_2 emissions maintaining a high contribution to CO_2 emission change (i.e. in excess of 100 %) throughout the 2020 to 2050 period. In contrast, the relative contribution of renewable energies to total emission reductions in all the remaining decarbonisation scenario declines throughout the 2020 to 2050 time frame and is progressively substituted by the emergence of either CCS technology (i.e. illustrated by the red bars in Figure 8) or improvements in energy efficiency. For example, the Energy efficiency scenario is characterised by both an increase in the efficiency rate of fossil fuel combustion and a decrease in electricity consumption throughout the 2020 to 2050 time horizon. The decline of nuclear energy use results in additional CO_2 emissions because it would need to be replaced by alternative sources of electricity production that may – under specific circumstances – be more CO_2

intensive. However, as Figure 8 demonstrates, the deployment of renewable energies alone in all scenarios is more than sufficient to offset additional emissions associated with a decrease in the use of nuclear energy.

4. Cost assumptions of the scenarios

All of the decarbonisation scenarios considered in this policy paper are characterised by a similar level of ambition, yet it is evident that the combination of abatement measures to deliver these CO_2 emission reductions vary. The cost assumptions of various power generation technologies are an important driving factor influencing the structure of electricity supply in all of the decarbonisation scenarios.[29] The aim of this section is to provide a transparent comparison of the various assumptions (fossil fuel price, technology costs) applied in these decarbonisation scenarios regarding the cost development of the various power generating technologies until 2050.

4.1 Fossil fuel costs

As in most energy models, cost assumptions are a crucial element in determining model results in the partial market equilibrium model (PRIMES) used. For the EU's Energy Roadmap 2050 modelling two different sets of assumptions have been made about the development of the market prices of fossil fuels. In the decarbonisation scenarios lower prices have been assumed than in the reference scenarios, based on the assumption that countries outside the European Union will also follow ambitious climate mitigation pathways and will thus reduce demand for fossil fuels, lowering world market prices as a consequence. Table 2 shows both the price assumptions in the two reference scenarios and the price assumptions in the five decarbonisation scenarios between 2015 and 2050 and contrast these with the respective assumptions in two other European energy scenario studies released within the past two years.

Table 2 Fossil fuel import prices (in €$_{2005}$) in the EU's Energy Roadmap 2050 scenarios compared to respective prices in other scenario studies

		Crude oil import price (€2005/barrel)	Natural gas import price (€2005/GJ)	Hard coal import price (€2005/tonne)
ECF Roadmap 2050	2015	55	6	57
	2030	73	9	69
	2050	73	9	69
Energy Revolution	2015	92	12	96
	2030	124	16	118
	2050	124	22	143
EU Energy Roadmap (baseline)	2015	74	8	111
	2030	98	12	147
	2050	118	15	151
EU Energy Roadmap (decarbonisation scenarios)	2015	71	7	98
	2030	73	9	116
	2050	65	7	93

Source: Öko-Institut / Wuppertal Institute (2012), compiled from (European Commission 2011d) and (European Commission 2011c)

In the EU's Energy Roadmap decarbonisation scenarios, it is assumed that the world market price of crude oil will remain relatively stable until 2030; after which the price is expected to steadily decrease steadily until 2050.[32] A similar development is assumed for natural gas, while the price for hard coal is expected to rise a bit between 2010 and 2030, before also dropping off until 2050. In summary it can be concluded that the fossil fuel price assumptions in the decarbonisation scenarios are at the lower end of current price scenarios. Higher price assumptions for natural gas and for hard coal would worsen the economics of CCS.

4.2 Technology costs

While the EU's Energy Roadmap 2050 does not provide specific electricity generation costs per technology, capital expenditure per unit of capacity is given for several technologies. Figure 9 shows a comparison of how capital expenditure changes over time for several renewable energy technologies in the EU's Energy Roadmap 2050 and in two other European energy scenarios.[33] For wind and especially solar PV relatively modest future cost reductions are assumed in the EU's Energy Roadmap 2050. For solar thermal on the other hand, costs are assumed to drop off considerably until 2050.[34] Interestingly, the EU's Energy Roadmap 2050 scenarios assume a steady decrease in the capital expenditure for new nuclear power plants, decreasing from around 4,380 $€_{2010}$/kW in 2010 to around 3,600 $€_{2010}$/kW in 2050. Considerable cost reductions over time, especially in the assumed early deployment phase between 2015 and 2030 are also assumed for power plants equipped with CCS. For example a coal CCS power plant (pulverised coal, supercritical) using the oxyfuel process reduces its capital expenditure from 3,480 $€_{2010}$/kW assumed for today to around 2,000 $€_{2010}$/kW by 2040. Compared to expectations from some other stakeholders and experts the EU's Energy Roadmap assumes only modest future cost reductions for the most important renewable energy technologies. This in combination with rather optimistic assumptions regarding the future cost reduction potential (and technological viability) of CCS technologies seems to lead to a relative disadvantage of renewable energy technologies in the electricity system in the PRIMES modelling.[35]

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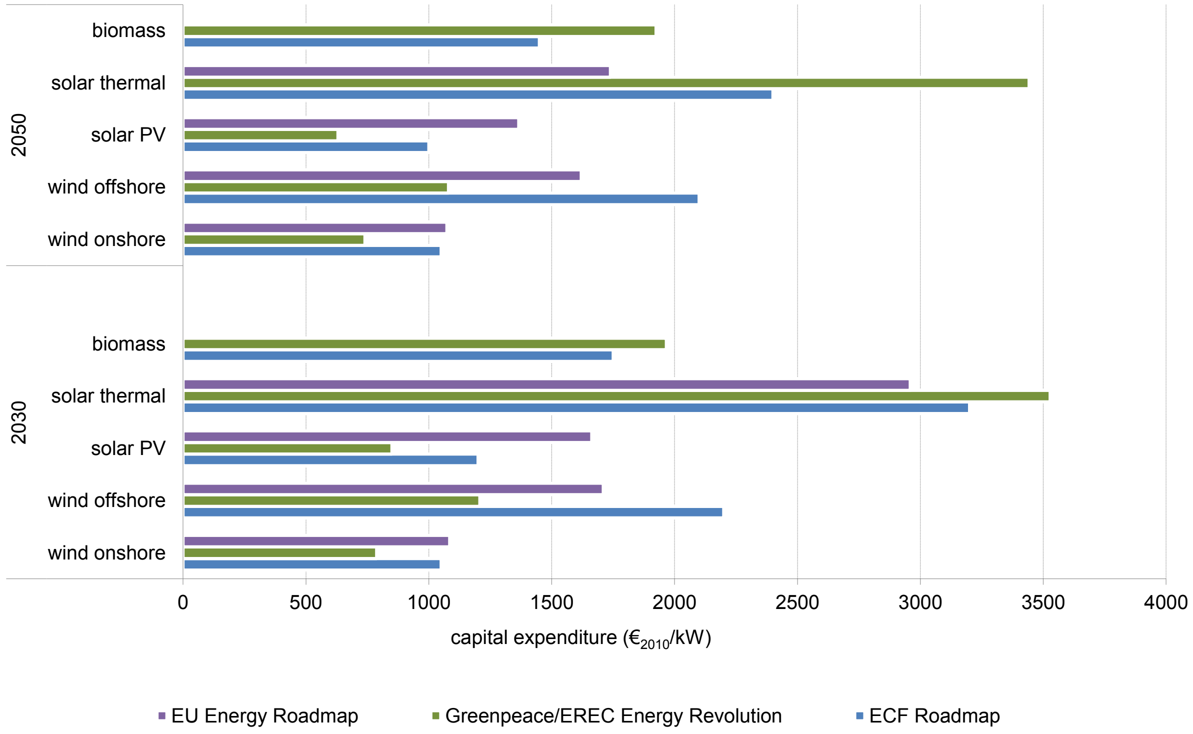
[32] While crude oil is of little direct importance to the electricity system, its price development heavily influences the prices of natural gas and coal.

[33] See the first policy paper within this project for more information about the cost assumptions in other European energy scenario studies.

[34] No information about the capital expenditure of biomass power plants is found in the EU's Energy Roadmap publications.

[35] It would be highly welcome in future EU energy modelling work if sensitivity analysis were to be performed and published on the effects of different fuel and technology cost assumptions on the energy system and specifically the average electricity price in various scenarios.

Figure 9 Comparison of assumptions on capital expenditure for several renewable energy technologies in several scenario studies (in €$_{2010}$/kW)



Source: Öko-Institut / Wuppertal Institute (2012), compiled from (European Commission 2011d)

5. Window of opportunity for political action

The window of opportunity for political action to prevent runaway climate change is rapidly closing as high-carbon energy generation facilities continue to be built around the world, resulting in an emissions 'lock in' effect that reduces the likelihood of limiting global temperature rise to a maximum of 2°C (likely requiring stabilization of atmospheric levels of greenhouse gases at no more than 450 ppm of CO_2 equivalent). According to (International Energy Agency 2011) a continuation of current trends in energy generation will result in 90 % of the available 'carbon budget' until 2035 being used up by 2015 already.[36] Political action at both the international and national level is therefore urgently required to incentivise low-carbon investments in order to decarbonise the world's energy generation. The purpose of this section is to provide further guidance on the timing of this political action from the European perspective by identifying the windows of opportunities for implementing important abatement measures that can be divided into the following categories:

- Existing abatement measures (i.e. renewable energies, fuel switching etc.)
- Key innovations (i.e. CCS technology, electric mobility etc.)

The outcome of the decomposition analysis outlined in Section 3 is re-organised in Table 3 to incorporate the above distinction between the evolutionary development of existing measures and the key innovations that require breakthroughs in technology to deliver the CO_2 emission reductions envisaged in the decarbonisation scenarios. Furthermore, the contribution of the causal factors to overall CO_2 emission changes is presented in relative terms to enable a better comparison between the decarbonisation scenarios and to complement Figure 6 and Figure 8.

The dark green shaded row in Table 3 illustrates that the deployment of renewable energy plays a central role throughout the 2020 to 2050 period in all of the decarbonisation scenarios; however there is a greater level of consensus on the short-term contribution to CO_2 emission reductions than in the longer term. The contribution of renewable energy to CO_2 emission changes in 2020 narrowly ranges from 140 % to 157 % relative to the base year for four of the decarbonisation scenarios (i.e. Energy efficiency, High RES, Diversified supply and Low nuclear) and reflects the renewable energy target set within the EU Climate Package. The contribution of renewable energy to CO_2 emission changes in 2020 is considerably lower in the Delayed CCS scenario (i.e. 102 % relative to the base year) and this is mostly due to the higher share of electricity generated in 2020 by nuclear energy according to this scenario. It is important that policy makers are aware of the potential for delays in the lead times that are associated with the deployment of renewable technologies and to legislate accordingly in order to ensure that this policy target is achieved by 2020.

Although renewable energy continues to plays an important role in reducing emissions until 2050, it is evident from Table 3 that in the medium to long term clear differences emerge amongst the decarbonisation scenarios with regards to both the implementation of CCS technology and the phase down of nuclear energy use. As a consequence, the contribution of renewable energy to CO_2

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[36] IEA (2011): World Energy Outlook 2011.

emission changes in 2050 declines in all of the decarbonisation scenarios compared to 2020, however the extent of this decline varies depending upon the use of alternative abatement options.

In all of the decarbonisation scenarios it is expected that improving the efficiency of fossil fuel plants and switching to cleaner fuel inputs (i.e. from coal to gas) will result in CO_2 emission reductions consistently throughout the 2020 to 2050 time period for all decarbonisation scenarios (Table 3). In order to encourage these improvements, political action will be required that progressively increases the cost of carbon until the year 2050, for which there exist a range of policy instruments (i.e. environmental taxes, emissions trading). Furthermore, the dark red shaded row in Table 3 demonstrates that the majority of the decomposition scenarios expect the role of nuclear power to decline by 2050, which will result in additional emissions that will need to be offset by introducing policies aimed at encouraging the rapid deployment of alternative sources of low carbon electricity generation (see column *RES use*) and improvements in energy efficiency.

Table 3 The contribution of existing abatement measures to CO_2 emission change compared to the base year of each scenario between 2020 and 2050.

		Resid. Cons.	Tertiary Cons.	Industry Cons.	Transport Cons.	RES Use	Nuclear Use	CCS Use	Emission Factor	Fuel Intensity
Energy efficiency	2020	-9%	-9%	-3%	-7%	146%	-38%	3%	-2%	20%
High RES		-14%	-15%	-4%	-6%	140%	-35%	4%	2%	32%
Diversified supply		-15%	-16%	-4%	-6%	143%	-37%	4%	2%	32%
Delayed CCS		-9%	16%	-2%	-4%	102%	-27%	3%	1%	23%
Low nuclear		-16%	-19%	-5%	-7%	157%	-43%	4%	11%	23%
Energy efficiency	2030	3%	3%	0%	-11%	103%	-31%	2%	10%	17%
High RES		-7%	-3%	0%	-11%	120%	-37%	2%	14%	21%
Diversified supply		-8%	-3%	-1%	-12%	109%	-26%	2%	15%	24%
Delayed CCS		-6%	12%	-1%	-9%	90%	-21%	2%	13%	20%
Low nuclear		-8%	-1%	-1%	-12%	122%	-50%	6%	22%	21%
Energy efficiency	2040	5%	5%	0%	-16%	81%	-24%	18%	10%	26%
High RES		-7%	1%	-2%	-19%	136%	-48%	7%	17%	30%
Diversified supply		-10%	-2%	-3%	-21%	94%	-26%	35%	11%	39%
Delayed CCS		-6%	11%	-3%	-13%	78%	-13%	11%	19%	24%
Low nuclear		-9%	0%	-2%	-19%	98%	-54%	49%	16%	38%
Energy efficiency	2050	6%	6%	1%	-14%	68%	-22%	28%	15%	26%
High RES		-4%	4%	-1%	-17%	125%	-46%	12%	32%	34%
Diversified supply		-7%	2%	-2%	-17%	77%	-24%	41%	23%	31%
Delayed CCS		-5%	10%	-1%	-13%	69%	-16%	28%	24%	23%
Low nuclear		-6%	2%	-2%	-17%	86%	-47%	55%	19%	33%

Note: This table has been turned around compared to Table 1: Scenarios are listed in the rows, while causal factors are listed in the columns. This is done in view of the time dimension that adds additional information to the table.

Positive values reflect emission reductions, negative values correspond to emission additions. A detailed breakdown on shares of causal factors on gross CO_2 emission reductions in each scenario can be found in the Annex.

Source: Öko-Institut / Wuppertal Institute (2012), results from decomposition analysis.

The commercialisation of CCS technology in the medium term is expected to contribute in several decarbonisation scenarios considerably to CO_2 emission reductions towards the end of the 2020 to 2050 time horizon. For example, the deployment of CCS technology will account for 55 % of emission changes (28 % of gross CO_2 emission reductions) in 2050 according to the Low nuclear scenario. A potential vulnerability to the realisation of these decarbonisation scenarios is the potential reliance on a single technology which is not yet in a commercial state. The assumption that CCS technology will become financially viable in the medium term depends to a large extent upon the level of investment in research and development that is provided to deliver the technological breakthroughs that are necessary. Therefore, decarbonisation scenarios dependent upon CCS technology for emission reductions rely upon the development of an abatement technology that is highly uncertain.

It is evident from Table 3 that the rising electricity demand over time for new appliances such as electric vehicles and heat pumps presents policy makers with even more urgency to successfully decarbonise the power sector by 2050 to prevent electric vehicles from contributing to CO_2 emissions in the future. Given the dependency of these new appliances on a low carbon electricity grid, political action is urgently required now to ensure that these key innovations can be increasingly utilised from 2020 onwards to reduce CO_2 emissions.

6. Conclusion

This paper identifies robust energy system strategies followed within the different Energy Roadmap 2050 scenarios. For these strategies political action is urgently required in order to deliver the 'shared vision' that the European Commission is aiming for with its decarbonisation scenarios. Given that the window of opportunity for political action to prevent the 'lock in' of carbon intensive technologies in the power sector is time-limited, it is essential that political action is taken within the next decade to implement the 'key innovations' for CO_2 emission reductions that were identified in the decomposition analysis and discussed in Section 5. Further political debate will be necessary to decide upon the more controversial elements of decarbonisation (i.e. the deployment of nuclear power and CCS technology in the energy mix) and this policy paper challenges the robustness of decarbonisation scenarios that are highly dependent on assumptions associated with high levels of uncertainty (i.e. commercialisation date of CCS).

The following three robust energy system strategies have been identified by the analysis of the Energy Roadmap 2050 scenarios[37]:

- **Efficiency improvements critical**
  The decomposition analysis has shown that efficiency measures aimed at reducing the growth of electricity demand compared to a reference development are absolutely crucial to achieve the decarbonisation of the power system as envisioned in the policy scenarios. Efficiency improvements not only allow limiting electricity demand growth but also enable significant amounts of electricity to be used in the heating and especially the transport sector, thus "exporting" CO_2 emission reductions to these sectors – given supply side technologies in the power sector are decarbonised in parallel.

- **Renewables are most important supply side mitigation option, while the role of nuclear power will be limited**
  In all of the decarbonisation scenarios technologies using renewable energy sources are by far the most important supply-side mitigation option in the electricity system. The role of nuclear energy on the other hand will decrease in all of the decarbonisation scenarios.

- **Fluctuating electricity sources to capture major share in power generation within the next four decades**
  Of all renewable energy sources wind is by far the most important one for the decarbonisation of the electricity system. Robust growth in wind power is expected already in the near-term as the technology, especially onshore wind, is relatively mature and among the most economically attractive low carbon electricity generation options. By 2050 wind onshore and offshore is responsible for more than 30 % of electricity generation in all of the decarbonisation scenarios and even for around 50 % in the High RES scenario. This also

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[37] These findings are largely in line with the respective findings of a previous analysis of other European energy scenarios conducted within this project (see SEFEP 2012). The main area of disagreement is in regard to nuclear power, as a few (pre-Fukushima) scenarios envision a more important role for this technology than the EU's Energy Roadmap 2050 scenarios

means that a large share of future electricity generation in Europe will be from fluctuating renewable energy sources (especially wind and solar PV). Policymakers should be aware of this and should prepare strategies early on for the electricity system to be able to deal with such a high share of fluctuating electricity supply.

In many of the decarbonisation scenarios **CCS technologies** also play an important role in reducing CO_2 emissions in the power sector. However, the High RES scenario indicates that the role of CCS may be limited when a high deployment of renewable technologies as well as their system integration will be successful. Even in the other scenarios, CCS is not expected to be deployed to any significant extent before 2030. This assumption about the relatively late relevance of CCS reflects current uncertainties about its technological viability and its economics, including infrastructure and CO_2 storage capacity. The high growth rate for CCS plants after 2030 and the assumed falling technology costs critically require both of these core CCS technology challenges to be solved by then, i.e. a significant technological maturity and sufficient public acceptance will be necessary.

Apart from the analysis of scenario results, the work within this project on the Energy Roadmap 2050 and on previous scenario studies has made it clear that the scenario studies themselves could be improved to further add to their relevance for energy policy making. Especially the following two issues should be addressed:

- **Need for greater transparency in scenario results**
  A few key assumptions, for example on specific generation costs and technological attributes (like the efficiencies of the various types of power plants and the capture rate assumed for CCS plants) as well as some key modelling results (like the amount of electricity generated in PV and CSP plants individually or in natural gas CCS and coal CCS plants) have not been made public and their availability would considerably help to analyse and better understand the reasons and implications of the differences in the seven Roadmap scenarios.

- **Sensitivity analyses could help explore effects of different technology price assumptions on electricity mix**
  It would prove useful if sensitivity analyses regarding crucial parameters were systematically applied to decarbonisation scenarios (for example capital cost assumptions). Such analyses would enable the exploration of capital cost corridors in which one or the other technology becomes economically viable.

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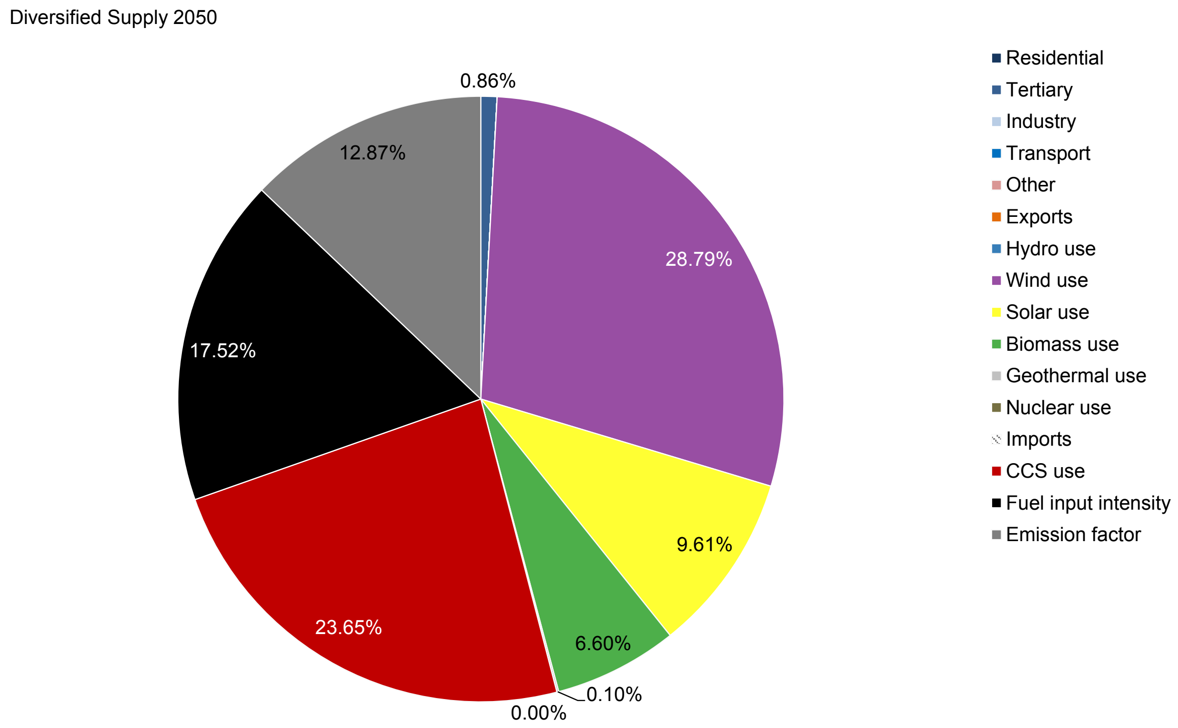
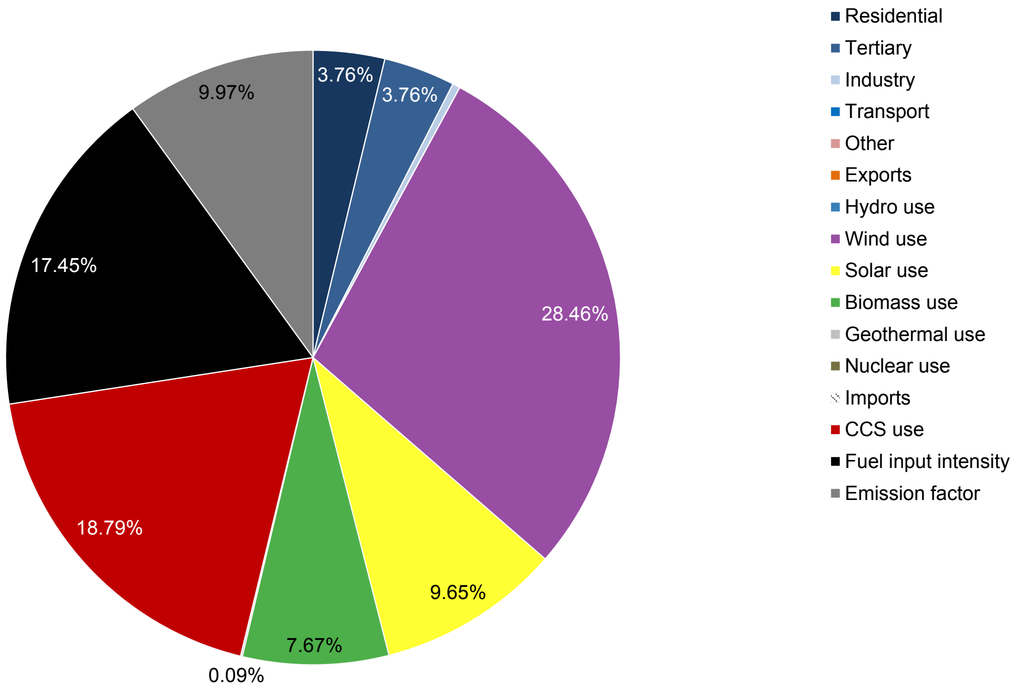
8. Annex

8.1 Shares of causal factors on gross CO_2 emission reductions in each scenario

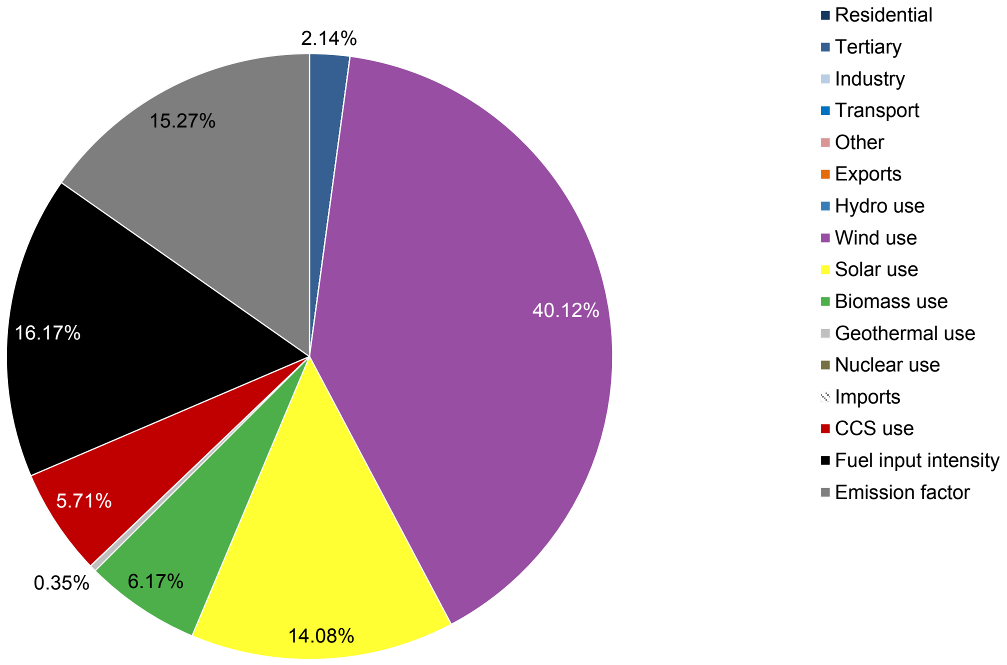
Figure 10 Shares of causal factors on gross CO_2 emission reduction in each scenario in 2050.

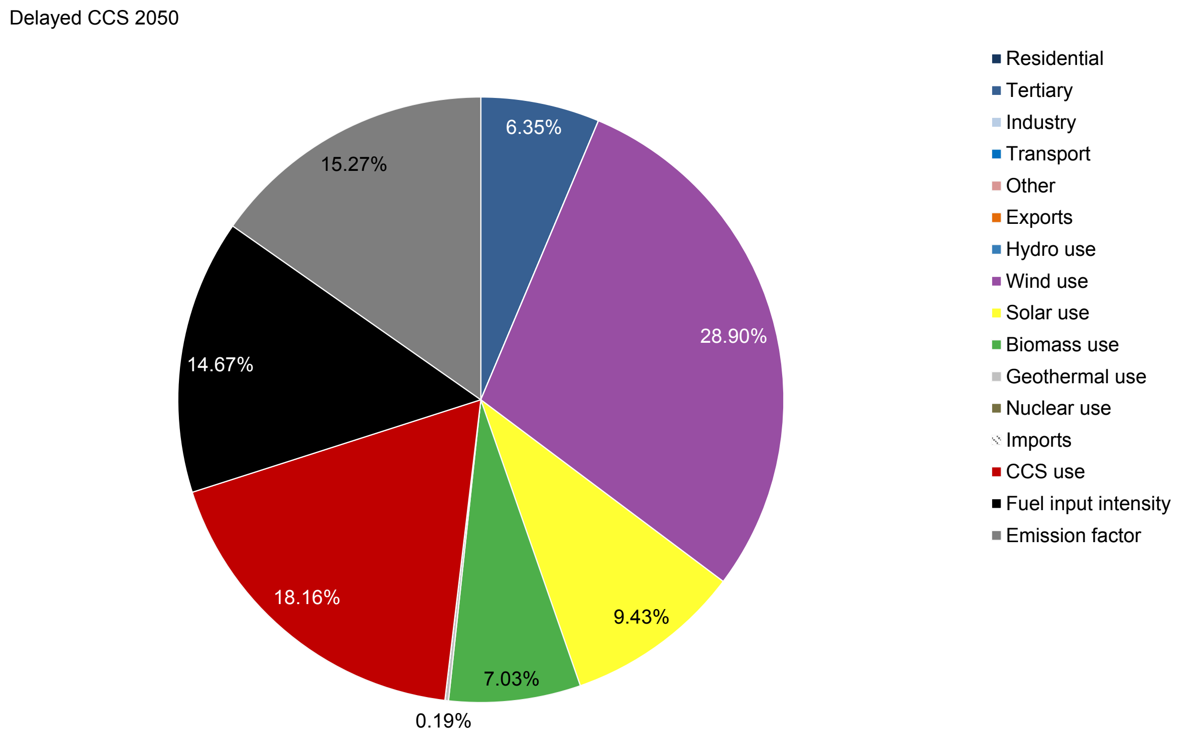


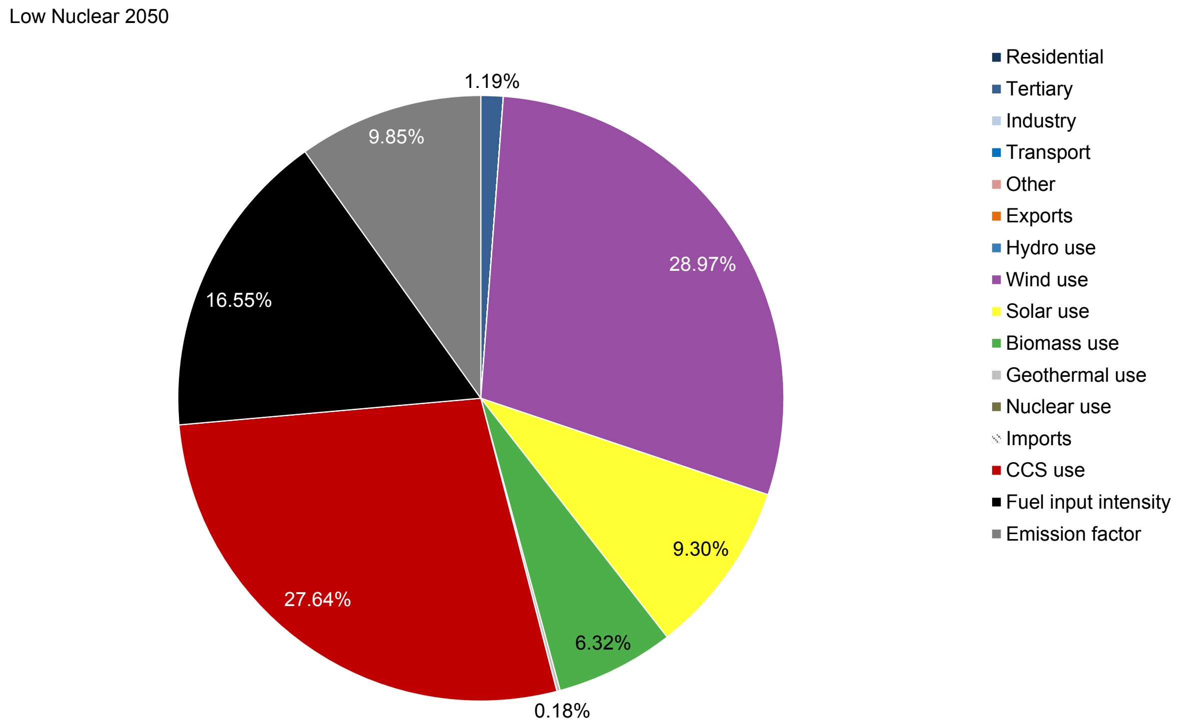
Energy Efficiency 2050



High RES 2050







Source: Öko-Institut / Wuppertal Institute (2010), results of decomposition analysis.

Climate Policies in the EU

In December 2008, the European Union (EU) adopted a comprehensive energy and climate package to further enhance the international reputation of the EU as a leader on climate policy. The objective of the energy and climate package is to reduce greenhouse gases (GHGs) by at least 20 % by 2020 relative to 1990 emission levels, increase the share of renewable energy in meeting the EU's final energy demand to 20 % and to reduce energy consumption by 20 % compared to projected trends.

An essential policy instrument to achieve these climate policy objectives is the Emissions Trading System (ETS), which was introduced in 2005 (Directive 2003/87/EC) and regulates over 11 000 installations that are responsible for almost half of the GHG emissions emitted in the EU. The ETS is based upon the principle of cap and trade, which can be briefly summarized as follows:

- A cap or limit on the total amount of particular GHG emissions that can be emitted is set for all factories, power plants or other installations participating in the EU ETS;
- Emission Unit Allowances (EUAs), which are equivalent to the emissions limit set under the cap, are distributed to the installations participating in the ETS;
- Installations are then required to surrender at the end of each year one EUA for each tonne of GHG which they have emitted;
- The ability to trade allowances enables installations that do not have enough allowances to cover their emission level for a compliance period by purchasing allowances on the market. In contrast, installations with a surplus of allowances can sell these on the market.
- These transactions creates a price per tonne of GHG that provides the financial incentive for installations to either reduce their level of emissions to sell their allowance surplus on the market or to buy allowances if this is more cost effective than reducing their own emissions.

The third trading phase of the EU ETS will commence in 2013 with the introduction of an EU wide cap on emissions, which will reduce at an annual rate of 1.74 % to ensure that the EU achieves a -21 % reduction in the ETS sector relative to 2005 emission levels (Directive 2009/29/EC). Emissions from sectors not covered by the ETS (i.e. buildings, transport and agriculture) are subject to the Effort Sharing Decision (406/2009/EC), which obliges the Member States to ensure that collectively non-ETS emissions are reduced by -10 % below 2005 levels by 2020. If the policies are fully implemented in both directives, it is envisaged that the EU objective of an economy wide reduction of -20 % below 1990 emission levels will be achieved by 2020.

National binding targets have been set for each Member State to ensure that the average renewable share across the EU reaches 20 % by 2020 (Directive 2009/28/EC). Given that the starting point, the renewable energy potential and the energy mix varies for each Member State, the EU target of 20 % was translated to individual targets that ranged from a renewables share of 10 % in Malta to 49 % in Sweden. If these national binding targets are achieved then the EU objective of increasing the share of renewable energy in meeting the EU's final energy demand to 20 % will also be achieved by 2020. To ensure that the energy efficiency objective is also achieved by 2020 the European Commission recently proposed new legislation (COM (2011) 370 Final) to obligate Member States to establish energy saving schemes.

8.2 Suggested standard for data reporting